Selected sections of Lower to Middle Ordovician carbonate sedimentation of the Argentine Precordillera: The La Silla and San Juan formations at Cerros La Silla and Niquivil

Fernando Cañas[1]

1 Departamento de Geología, Universidad Nacional de Río Cuarto, Ruta 36 Km. 601. Río Cuarto X5804BYA. Córdoba. Argentina.

Key words: Stratigraphy. Biostratigraphy. Lower-Middle Ordovician. Carbonate sedimentation. Precordillera. Argentina

Introduction

The Cerros La Silla and Niquivil were areas of active research since the late 80's, as they stand as two of the best exposed and accessible sections for the Lower to Middle Ordovician carbonates of the Argentine Precordillera. Graduate and postgraduate students from the University of Córdoba (*e.g.*, del Papa, 1988; Cañas, 1995), the University of Erlangen—Nürnberg (Lehnert, 1990), and many paleontologic, stratigraphic and sedimentologic contributions (*e.g.*, Herrera and Benedetto, 1991; Keller *et al.*, 1994; Lehnert, 1993, 1995; Cañas, 1995, 1999; Cañas and Carrera, 1993; Carrera, 2001; Cech and Carrera, 2002; Vaccari, 2001) supported the development of a well established litho- and biostratigraphic framework for the Lower Ordovician in the Precordillera.

The objectives of this field trip are:

- to visit two well studied localities representative of the Cambro—Ordovician carbonate platform of the Argentine Precordillera, the Cerros La Silla and Niquivil sections, the former being the type section for the two main Formations in which the Lower to Mid Ordovician carbonates have been divided;
- to document sedimentary facies associations, trace fossil associations, reef types and fossil concentrations in a nearly continuous succession spanning from the Upper Cambrian to the Middle Ordovician;
- to document three major events of platform reorganization, as recorded by different carbonate depositional systems widely distributed in the Precordillera: the Upper Cambrian peritidal platform (La Flecha Formation), the Tremadocian restricted shelf (La Silla Formation), and the upper Tremadocian—Mid Ordovician open shelf (San Juan Formation);

- to visit the Niquivil section, proposed *GSSP* for the Lower/Middle Ordovician boundary (Albanesi *et al.*, 2003).

Geologic setting and stratigraphic framework

The Argentine Precordillera is a thin-skinned, mainly east-verging fold and thrust belt, constituted predominantly by Paleozoic and Cenozoic deposits. The present morphology is controlled by Andean (Neogene—Recent; Jordan *et al.*, 1983), north-striking, westward-dipping imbricate faults, responsible for east-west shortening of at least 50% (von Gosen, 1992). The orogenic belt stretches through the La Rioja, San Juan and Mendoza Provinces from north to south (28º45'S—33º15'S) more than 400 km, bounded by the Frontal and Main Andes to the west, and a Precambrian to Lower Paleozoic metamorphic basement of the Sierras Pampeanas to the east (Fig. 1A).

Although a Precambrian basement is not exposed in the Precordillera, it is known from Grenvillian age xenoliths occurring in Tertiary volcanic rocks (Abbruzzi *et al.*, 1993). Grenvillian age basement rocks crop out immediately to the east of the Precordillera in the Western Sierras Pampeanas, and together are considered to integrate an exotic lithospheric block. With ca. 800—1000 km in extension, this terrane known as Cuyania (Fig. 1A) exceeds the limits of the Precordillera, reaching to the south the Province of La Pampa (Astini *et al.*, 1996; Melchor *et al.*, 1999). In recent years, a general consensus has been achieved about the Laurentian origin of this microcontinent, supported by paleontologic, stratigraphic and geologic evidences (*e.g.,* Astini *et al.*, 1995, 1996; Dalziel *et al.*, 1996; Thomas and Astini, 1996, 1999), though this interpretation has recently been challenged based mainly on U/Pb ages of detrital zircons form Lower Paleozoic quartz sandstone beds from both the Precordillera and Sierras Pampeanas (Finney *et al.*, 2003). Also, the timing of rifting, transfer and docking of the terrane to Gondwana is still subject to much debate (see Thomas and Astini, 2003, and references therein).

An outstanding feature of the Lower Paleozoic rocks exposed in the Argentine Precordillera is the development of a thick succession (2.0—2.5 km) of Cambro—Ordovician platform carbonates, that strongly contrasts with the clastic and volcaniclastic wedges developed at the same time elsewhere at the western Gondwanan margin. Shallow-water limestones and dolostones are widely distributed in the eastern and central ranges of the Precordillera, whereas to the west they are tectonicaly juxtaposed with clastic slope and deep-basinal rocks (Western Tectofacies of Astini, 1992; Fig. 1B). Platform carbonates also graded northwards into deeper, outer ramp to intrashelf-basinal deposits by the Mid Ordovician (Cañas, 1995). Carbonate sedimentation ceased in the Precordillera until the Late Ordovician, when the platform was drowned as recorded by widespread deposition of graptolitic black shales (e.g., Astini, 1994). Fig. 2 summarizes the stratigraphy of the carbonate succession. A revision of the lithostratigrapic framework of these units was presented by Keller *et al.* (1994).

The Cerros La Silla and Niquivil Sections

Located about 15 km to the southeast of Jáchal City by the eastern margin of the Jáchal River, the Cerro La Silla comprises a thick succession of Upper Cambrian to Middle Ordovician carbonates dipping to the west, forming the first (easternmost) of a series of east-directed thrusts (Fig. 1C). Exposed in the section are the Upper Cambrian (upper Marjuman—upper Sunwaptan) La Flecha Formation, the Lower Ordovician (uppermost Sunwaptan—upper Tremadocian) La Silla Formation, and the Lower to Middle Ordovician (upper Tremadocian—Darriwilian) San Juan Formation. Both, the base and top of the homoclinal succession are not exposed, covered by Holocene deposits. At the southern tip of the Cerro La Silla, the Niquivil section is situated in the Niquivil Village, 22 km south of Jáchal City, beside the western margin of the Jáchal River (Fig. 1C). In this section, only the upper part of the succession crops out (lower –but not the base– and middle parts of the San Juan Fm.).

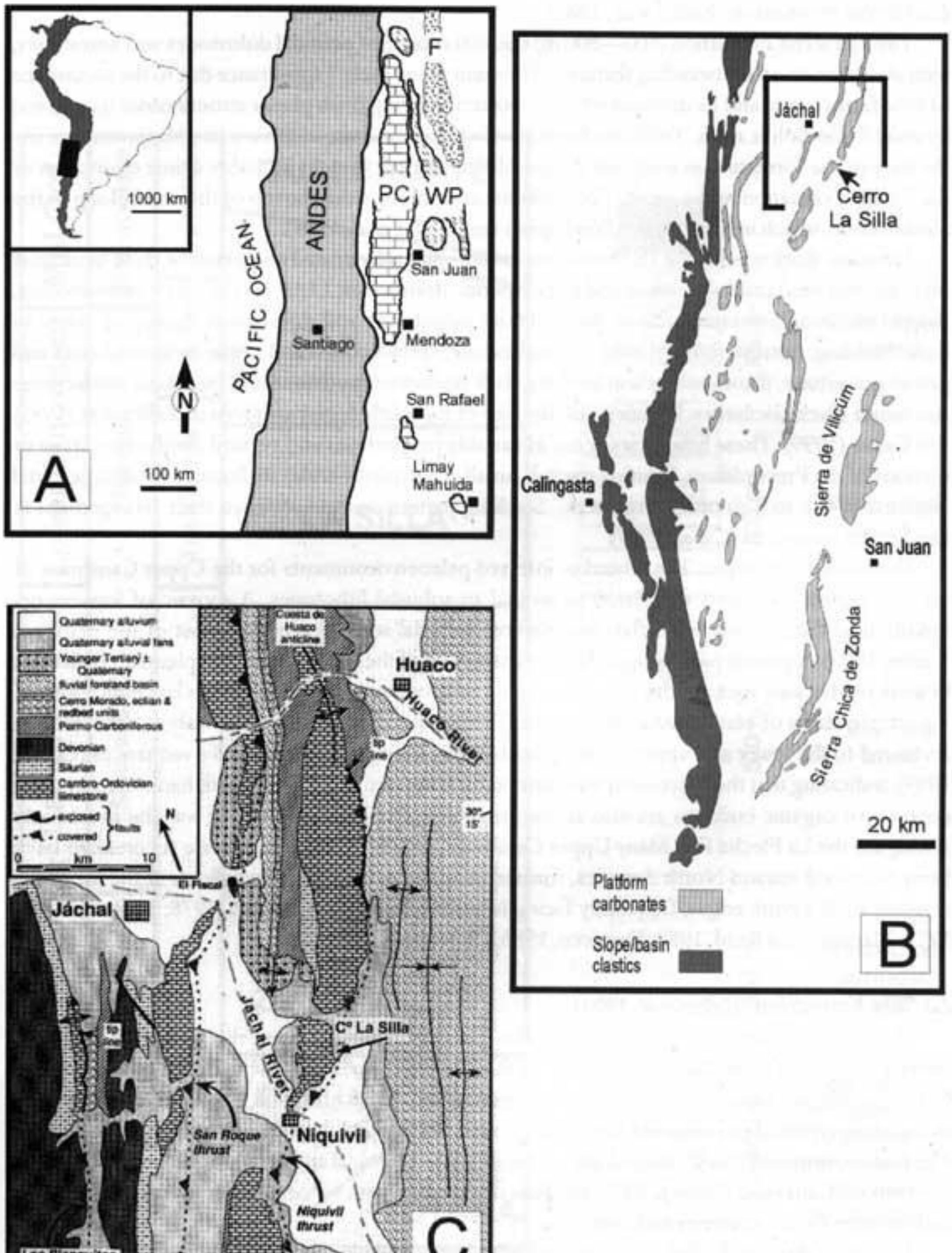

Fig. 1. A. Location of the Cuyania terrane (Precordillera: PC + Western Pampeanas ranges: WP). F: Famatina Ranges. B. Distribution of Cambro-Ordovician rocks within the Precordillera; rectangle indicates the area of interest for this field trip. C. Geologic map spanning three E-verging thrusts, showing the geological situation of the La Silla – Niquivil range (modified from Jordan et al., 1993).

Fig. 1. A. Location of the Cuyania terrane (Precordillera: PC + Western Pampeanas ranges: WP). F: Famatina Ranges. B. Distribution of Cambro-Ordovician rocks within the Precordillera; rectangle indicates the area of interest for this field trip. C. Geologic map spanning three E-verging thrusts, showing the geological situation of the La Silla – Niquivil range (modified from Jordan et al., 1993).

La Flecha Fromation (Baldis *et al.*, 1981)

The La Flecha Formation (500—800 m) consists mostly of peritidal dolostones and limestones, with abundant chert. Outstanding features of this unit are a "cyclic" appearance due to the recurrence of lithofacies types, and its diversity of microbialites, ranging from planar stromatolites (laminites) to small thrombolitic reefs. Trilobites from the *Crepicephalus* Zone indicate a late Marjuman age for the base of the formation in northern Precordillera, where it is most probably a time equivalent of the Zonda Formation to the south. Poor trilobite collections from the top of the unit belong to the *Saukia* Zone, which indicates a late Sunwaptan age (Keller *et al.*, 1994).

Lithofacies. Rock types in the La Flecha Fm. include: planar laminated microbialites, thick-laminated (may present mud cracks) peloidal and microsparitic dolostones, LLH- and SH-type stromatolites, flat-pebble conglomerates, ribbon (heterolithic) limestones and dolostones displaying wavy to flaser bedding, burrow-mottled mud- to wackestone, cross-bedded and ripple-laminated ooid and peloid grainstone, thrombolites and leiolites, dark burrowed mudstone and bioclastic wackestone and minor black calcilutites. Detailed descriptions of these lithologies are given in Keller *et al.* (1989) and Cañas (1999). These lithofacies occur in variable proportions and vertical displays in different sections of the Precordillera, forming stacked, small-scale (meter-scale) shallowing-upward peritidal sequences (4-th to 5-th order sequences). Stacking pattern analysis revealed their arrangement in third-order sequences (Cañas, 1999).

Depositional environment. The record of inferred paleoenvironments for the Upper Cambrian of the AP includes a variety of related supratidal to subtidal lithotopes. A mosaic of low-energy muddy tidal flats, shoals, sand flats and shallow subtidal settings covered most of the platform (Cañas, 1999). A precise paleogeographic reconstruction of the Upper Cambrian platform is difficult to work out because rocks of this age crop out in a relatively narrow belt, without clear indications of the actual polarity of platform during that time. Terrigenous clastic grains occur only as traces and are restricted to the lower and upper parts of third-order, transgressive-regressive sequences (Cañas, 1999), indicating that the succession was formed far from any shore-line. Thick bank-margin shoal deposits or organic buildups are also absent, suggesting that a shelf interior was the most likely setting for the La Flecha Fm. Many Upper Cambrian stacked peritidal carbonate successions have been described around North America, formed on extensive tidal flat complexes at the lee of the regional shelf's bank edges, frequently facing intrashelf-basins (*e.g.,* Aitken, 1978; Mazzullo *et al.*, 1978; Markello and Read, 1982; Demicco, 1985; Chow and James, 1987).

La Silla Formation (Keller *et al.*, 1994)

The La Silla Formation (300—400 m) lies (para)conformably upon the La Flecha Fm. The contact was placed at the lowest occurrence of thick-bedded limestones, which at the type section of Cerro La Silla are filling a cm- to m-scale erosive relief on top of the La Flecha dolostones. This surface is interpreted as a sequence boundary (Cañas, 1999; type-1 sequence boundary, Keller, 1999). The unit is composed chiefly of medium- to thick-bedded peloidal and ooid limestones, thrombolite biostromes (Cañas and Carrera, 2003) and lime mudstones, with subordinate amounts of laminated and stromatolitic dolostones and chert (Fig. 3).

The age of the La Silla Fm. has been established by conodonts and sparse trilobites (Keller *et al.*, 1994; Lehnert, 1995; Lehnert *et al.*, 1997; Albanesi *et al.*, 1998a). The trilobite *Plethopeltis obtusus*, which in North America ranges from the *Saukia* to the *Missisquoia* trilobite zones, has been found near the base of the unit (Vaccari, 1994) indicating a late Sunwaptan age for this levels. Four conodont associations were described from four points (B through E) of the La Silla Fm. (Keller *et al.*, 1984; Lehnert, 1995). The oldest recorded conodont faunas of the formation occur about 55 m from the

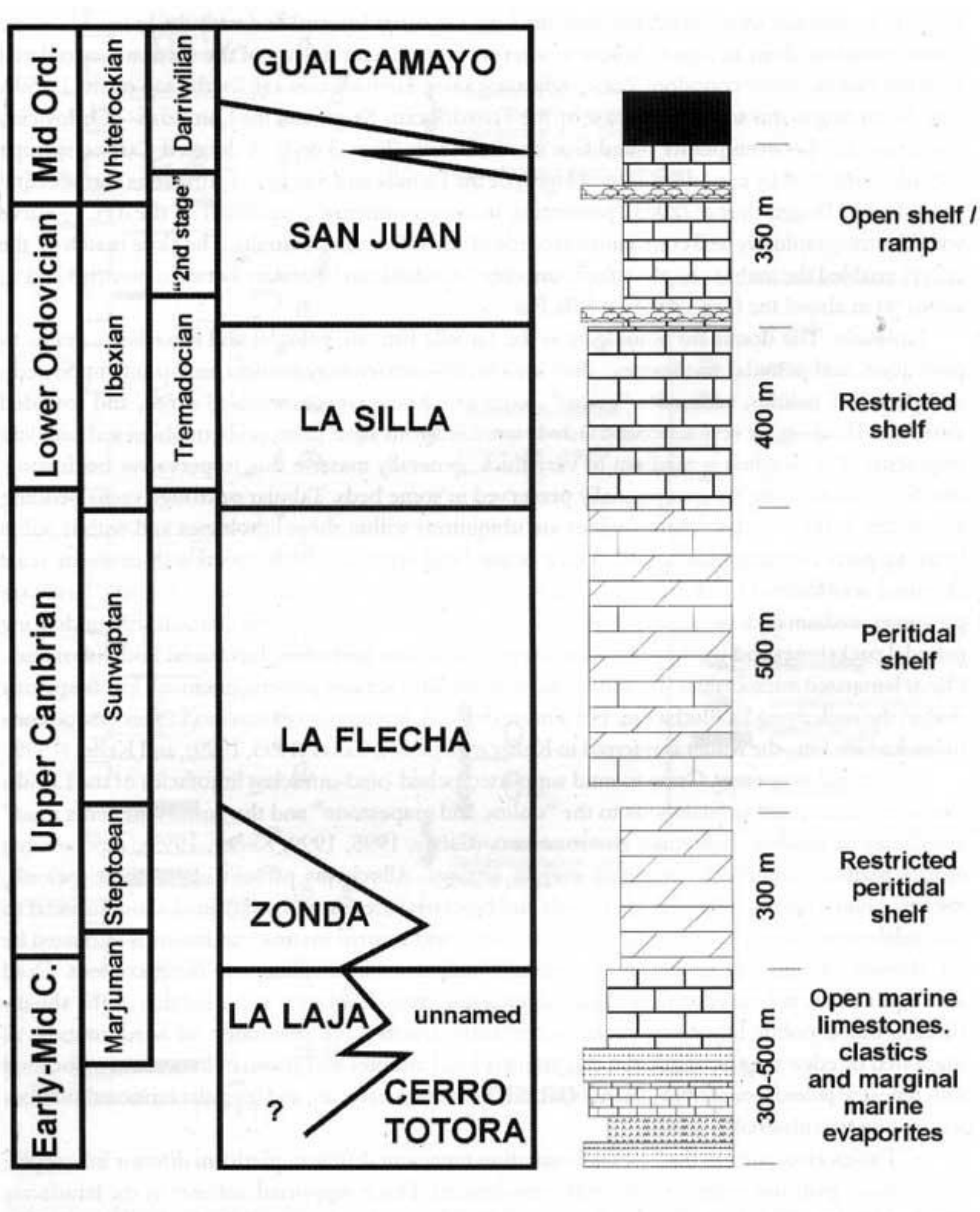

Fig 2. Stratigraphy of the Cambro-Ordovician carbonate platform units.

Fig 2. Stratigraphy of the Cambro-Ordovician carbonate platform units.

base (point B in the section, Figs. 3 & 4), and consists of an association containing the species *Clavohamulus hintzei*, diagnostic of the *Clavohamulus hintzei* conodont Subzone of the *Cordylodus intermedius* Zone. The next conodont fauna (point C in the section, Figs.) was correlated with the *Rossodus manitouensis*conodont Zone of the

Skullrockian Stage (Ibexian Series) of North America. Point D conodonts were correlated with the Low Diversity Interval and with the lower *Macerodus dianae* conodont Zone in North America, whereas point E near the top of the section is correlated with the *Paltodus deltifer*conodont Zone, indicating a late Tremadocian age for the top of the La Silla Fm. According to this scheme, the base of the Tremadocian Stage (and the Cambrian—Ordovician boundary) lies between points B and C at Cerro La Silla (Figs. 3 & 4). A detailed Carbon isotope record (controlled by conodont assemblages) of the La Silla and San Juan formations was recently published by Buggisch *et al.* (2003), presenting an intercontinental correlation of the d13Ccarb curve with biostratigraphicaly well constrained records of the U.S.A. and Australia. The close match of the curves enabled the authors to place the Cambrian—Ordovician boundary between points B and C, about 90 m above the base of the La Silla Fm.

Lithofacies. The dominant lithologies in the La Silla Fm. are peloidal and intraclastic grain- to packstone, and peloidal wackestone; they are chiefly calcarenites (grain to lime-mud supported), composed of peloids, carbonate "grains", aggregate lime grains, micritized ooids, and rounded intraclasts. Bioclasts are very scarce and include rare calcareous algae, gastropods, trilobites and nautiloid fragments. The bedding is medium to very thick, generally massive due to pervasive burrowing: silicified *Thalassinoides* are exceptionally preserved in some beds. Tabular or trough cross bedding also occur in these facies. Thrombolites are ubiquitous within these lithologies and within oolite beds, in parts forming biostromes. Thick oolite beds with uni- or bidirectional, medium scale crossbed sets formed by clean, well-sorted ooid grainstones have sharp bases. Erosive bases are present in medium beds of oolitic-lithoclast lime conglomerates. Gradational contacts with underlying peloidal packstones and wackestones also are present where burrowing has mixed both lithofacies. Planar laminated microbialites (laminites) and stromatolites are also present, but much less frequently than in the underlying La Flecha Fm. For a more detailed description of facies and facies associations of the La Silla Fm., the reader is referred to Keller *et al.* (1994), Cañas (1995, 1999), and Keller (1999).

Depositional environment. Grain to mud supported peloid-ooid-intraclast lithofacies of the La Silla Fm. were interpreted as analogous to the "oolitic and grapestone" and the "mud and pellet mud" lithofacies of modern Bahamian environments (Cañas, 1995, 1999; Keller, 1999), representing mostly platform interior to platform margin settings. Allochems present in this unit (peloids, micritic grains, lumps and micritized ooids and bioclasts) are formed today in shallow subtidal to intertidal environments. A subtidal lithotope under near normal marine conditions is indicated by the absence of evidence of subaerial exposure, ubiquitous burrowing, and fossil content. Ooid shoals punctuate the succession, and mixed sand-mud flats developed at the lee side of the shoals. Erosive-based oolitic-lithoclasts seem to represent storm-wave reworking of hardgrounds, as suggested by edge-wise arranged flat clasts. Microbial laminites and stromatolites occur associated with fenestral peloidal mudstone, flat pebble and dissolution breccias, and irregular erosional surfaces accounting for subaerial exposure.

Facies associated in the La Silla Formation represent different platform interior lithotopes, and probably platform-margin related subenvironments. This is supported not only by the lithofacies which are comparable to modern and ancient "shelf-lagoon" sediments, but also by the exclusion of both land-derived siliciclastics and open marine deposits.

San Juan Formation (*sensu* Keller *et al.*, 1994)

The San Juan Formation (400 m) is the topmost unit of the platform carbonates succession in the Precordillera (excluding some isolated occurrences of Upper Ordovician carbonates); at the type-

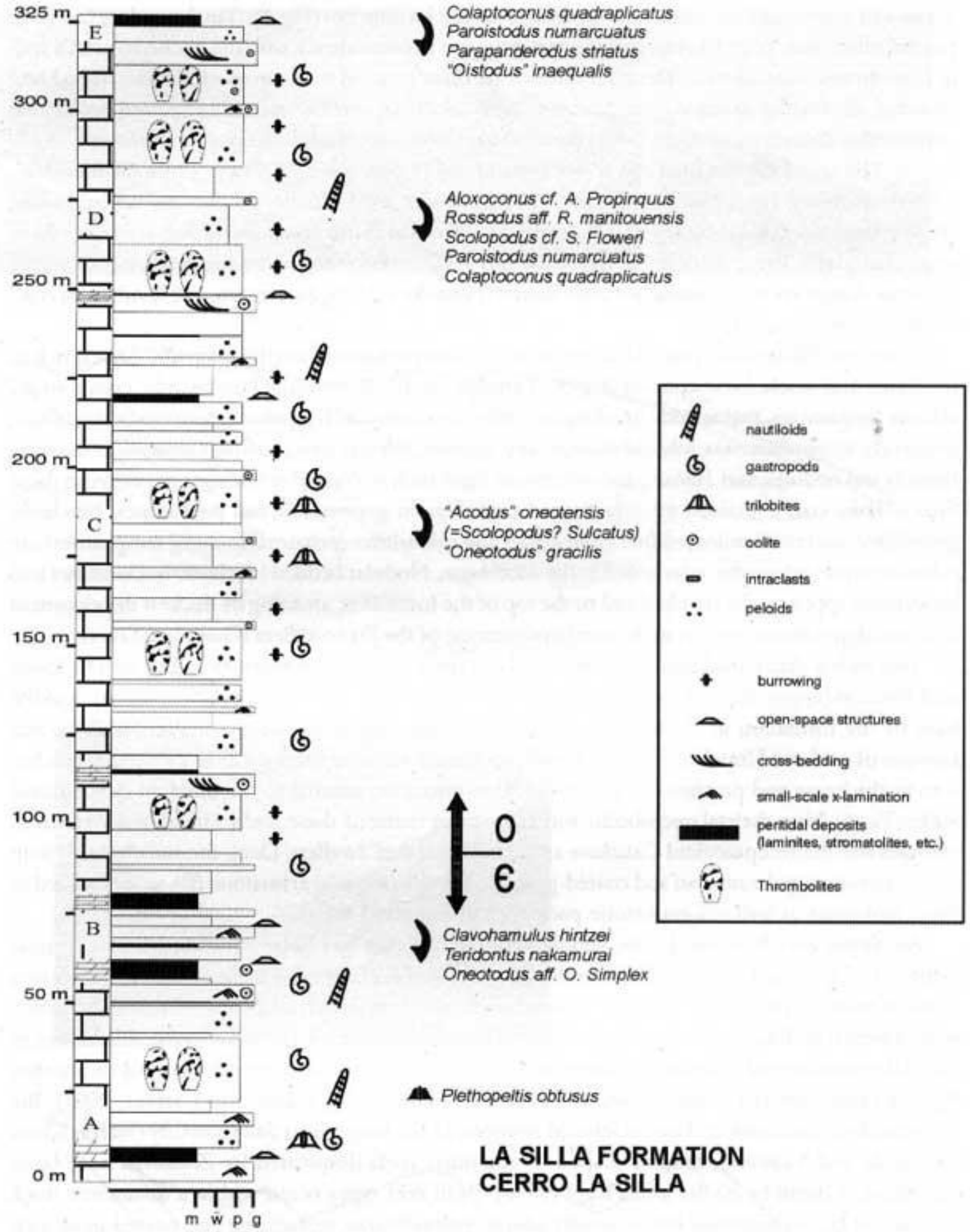

Fig. 3. Stratigraphic column of the La Silla Formation at the type Cerro La Silla section. Trilobite symbol shows approximate position of fossiliferous spot above point A; conodont symbols indicate position of points B through E and associated species. See text for inferred position of the Cambrian—Ordovician boundary.

Fig. 3. Stratigraphic column of the La Silla Formation at the type Cerro La Silla section. Trilobite symbol shows approximate position of fossiliferous spot above point A; conodont symbols indicate position of points B through E and associated species. See text for inferred position of the Cambrian—Ordovician boundary.

section of Cerro La Silla, it lies conformably over the La Silla Fm (Fig. 4). The boundary has been placed where thin, platy to nodular limestones appear in coincidence with the occurrence of a full-marine diverse macrofauna. These limestones are distinguished by a conspicuous pseudobedding showing alternating massive, gray horizons and "nodular", yellow to tan weathered levels that concentrate dolomite and argillaceous material in solution seams and compacted burrows.

The age of the San Juan Fm. is well constrained by conodonts (Lehnert, 1995; Albanesi *et al.*, 1998a) spanning from the late Tremadocian (*Paltodus deltifer* Zone) to the early Darriwilian (*Eoplacognathus suecicus* Zone) stages. However, the top of the formation is diachronic from northern (e.g., Guandacol River section; i.e, *Oepikodus evae – O. communis* zones) to southern sections (e.g., Villicum Range section; *Lenodus variabilis* Zone) (Hünicken, 1985; Sarmiento, 1985; Albanesi *et al.*, 1998b; Albanesi *et al.*, 1999).

Lithofacies. Skeletal and intraclastic wackestones and packstones are the main lithologies, rich in bioclastic and whole fossil content (Fig. 5). Varieties can be distinguished on basis of components relative frequencies, that include brachiopods, trilobites, crinoidal fragments, gastropods, nautiloids, ostracods, receptalitaceans, lithistid sponges and spicules, calcibacteria (notably *Girvanella* as oncoids, threads and nodules, and *Halysis*), and calcareous algae such as *Nuia*. Burrowing is pervasive in these facies. Thin, coarse grained intraclastic and coated-grain grainstones and packstones, bioclastic grainstone, and thin laminated fine grainstones and calcisiltites (proximal to distal tempestites) are other common lithofacies interbeded in the succession. Nodular bedded bioclastic wackestones and mudstones appear in the first half and to the top of the formation, attaining its thickest development at a local depocenters such as in the northern extreme of the Precordillera (Guandacol area).

Two widely distributed reef horizons stand out from sections this formation (Fig. 5). The lower reef horizon (upper Tremadocian), described in detail by Cañas and Carrera (1993), occurs near the base of the formation in most outcrops around Jáchal City in the northern Precordillera, and consists of coalesced (rarely isolated) mounds, forming a massive, continuous bioherm that reaches 4 m in thickness and pinches out in 100—150 m measured normal to the inferred depositional strike (Fig. 6). Non-skeletal microbialite forms the main frame of these reefs, with abundant lithistid sponges and the receptaculitid *Calathium* as the principal reef dwellers. Deep-incised channels with coarse intraclast, pelmatozoan and coated-grains (*Girvanella* oncoids) grainstone fills are associated to these bioherms, as well as a grainstone-packstone intermound-facies.

An upper reef horizon (lower Middle Ordovician) that has been correlated through most outcrops of the San Juan Formation in the Precordillera (Lehnert and Keller 1993) contains two types of reefs. In the Jáchal area (*e.g.*, Cerros La Silla and Niquivil) reefs of this horizon are meter-scale domical to doughnut shaped reefs formed mainly by non-skeletal microbialite, in addition to skeletal cyanobacteria (*Girvanella, Wetheredella*), *Zondarella* (a probable stromatoporoid or another type of cyanobacterial construction, *see* Keller and Flügel, 1996; Cañas and Carrera, 2003), the receptaculitid *Calathium*, and minor lithistid sponges. In the ranges near San Juan City (Sierras Chica de Zonda and Villicúm), mound-shaped to columnar reefs dominated by *Zondarella* have been described in detail by Keller and Flügel (1996). Both reef types occur within a distinctive thick package of grain-supported rocks, mostly coarse, pelmatozoan, intraclastic and coated-grain rich grainstones that stands out the mid part of the San Juan Fm. in most sections. Cross-bedding, planar lamination, ripple-drift lamination and channel fills are common in this horizon.

Depositional environment. Lithofacies of the San Juan Fm. have been grouped by Cañas (1995, 1999) into five facies associations representing a spectrum of environments ranging from tidal and wave agitated shoal environments to deeper, sub-storm wave base, basinal settings, distributed along an open-shelf to ramp profile. Relative position to the fair weather and storm wave bases was

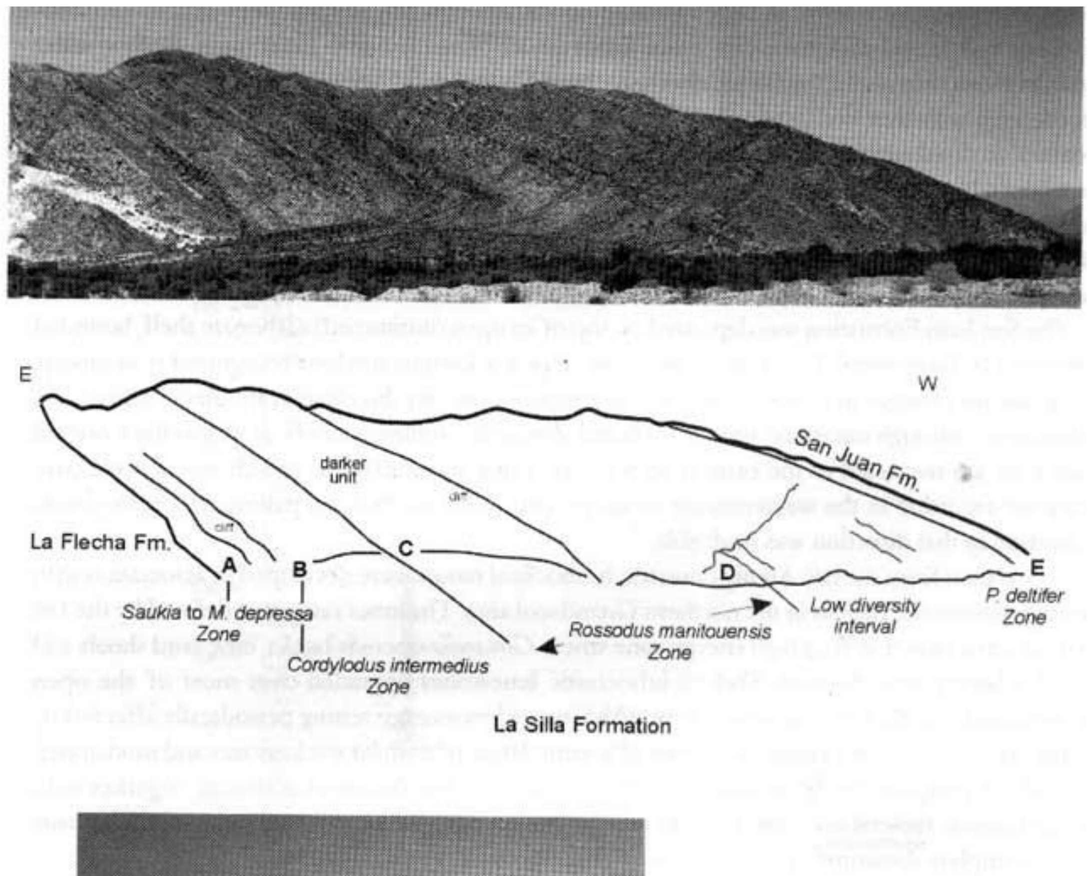

Fig. 4. The complete uppermost Cambrian through Middle Ordovician section at Cerro La Silla, sketching the boundaries of the La Silla and San Juan Formations and approximate distribution of the conodont biostratigraphic frame.

Fig. 4. The complete uppermost Cambrian through Middle Ordovician section at Cerro La Silla, sketching the boundaries of the La Silla and San Juan Formations and approximate distribution of the conodont biostratigraphic frame.

most likely the main control in facies association distribution (Fig. 7). The reef and intraclastic-bioclastic and oncoid packstone-grainstone facies associations formed in inner ramp, shallow-water shoals in facies belts above the fair weather wave base. Skeletal-bioclastic wackestones and packstones interbedded with thin beds of coarse lithoclast/oncoid grainstone and packstone, interpreted as proximal to distal tempestites, formed in a mid-ramp position, between the fair weather and storm wave bases. Nodular bioclastic wackestone and mudstone were deposited in the distal ramp, below the storm wave base, and parted limestones and black shales represent distal ramp to basinal settings. For a more detailed description of facies and facies associations of the San Juan Fm., the reader is referred to Keller *et al.* (1994), Cañas (1995, 1999), and Keller (1999).

The San Juan Formation was deposited on top of an open (unrimmed) carbonate shelf, bounded to the west by continental slope and oceanic basin deposits. Despite this long recognized relationship, no significant changes in facies associations are recorded in this direction in the shallow platform carbonates. Although microbial-sponge reefs and *Zondarella* dominated reefs, as well as thick oncoid grainstone are restricted to the eastern sections, no thick accumulations of sub-storm wave base facies are recorded in the westernmost sections. This indicates that, on palinspastic restoration, inclination in that direction was negligible.

At least from the late Arenig onwards, homoclinal ramps were developed in association with a local depocenters, such as in the northern Guandacol area. The inner ramp was defined by the fair weather wave base (FWB), a high energy zone where *Girvanella*-oncoids banks, lime sand shoals and small bioherms were formed. Skeletal-lithoclastic limestones aggraded over most of the open platform and middle ramp environments, which was a low-energy setting periodically affected by storms, whereas the outer ramp was the site of accumulation of nodular wackestones and mudstones, probably as periplatform hemipelagic muds derived from the shallower platform, together with autochthonous skeletal material. This association occurs onto the platform as outer-shelf deposits before complete drowning in the Darriwilian (Fig. 7).

For a sequence stratigraphic analysis based on vertical facies-association distribution (Fig. 8), the reader is referred to Cañas (1999) and Keller (1999).

Field Trip Stops

Stop 1. Morning: Cerro La Silla

This stop aims to familiarize you with the stratigraphy and basic lithologies of the platform carbonate rocks; to demonstrate 3 major facies associations corresponding to the La Flecha, La Silla and San Juan Formations, which represent three stages with different platform configurations in the evolution of the Cambro—Ordovician carbonate bank; and to show one of the best exposed and complete sections of the Lower Ordovician in the Precordillera.

The stop includes:

— From the road, superb view of the complete Upper Cambrian—Middle Ordovician succession. The lower unit with a "cyclic" appearance, delineated by color contrast of dark (dolo) mudstones and lighter, tan-weathering dolomite, represents the La Flecha Formation (Upper Cambrian). The thick-bedded, light to bluish gray limestones in the middle part of the succession is the La Silla Formation (uppermost Cambrian—upper Tremadocian). The upper unit in the succession is the San Juan Formation (upper Tremadocian—lower Darriwilian), characterized by fossiliferous, gray and tan-weathered colors, thin, platy to unevenly bedded dolomitic limestones. Another striking feature of this unit is an apparent alternation of "fissile" beds that weathers out as rubble, and "compact" beds, producing a marked (pseudo)bedding.

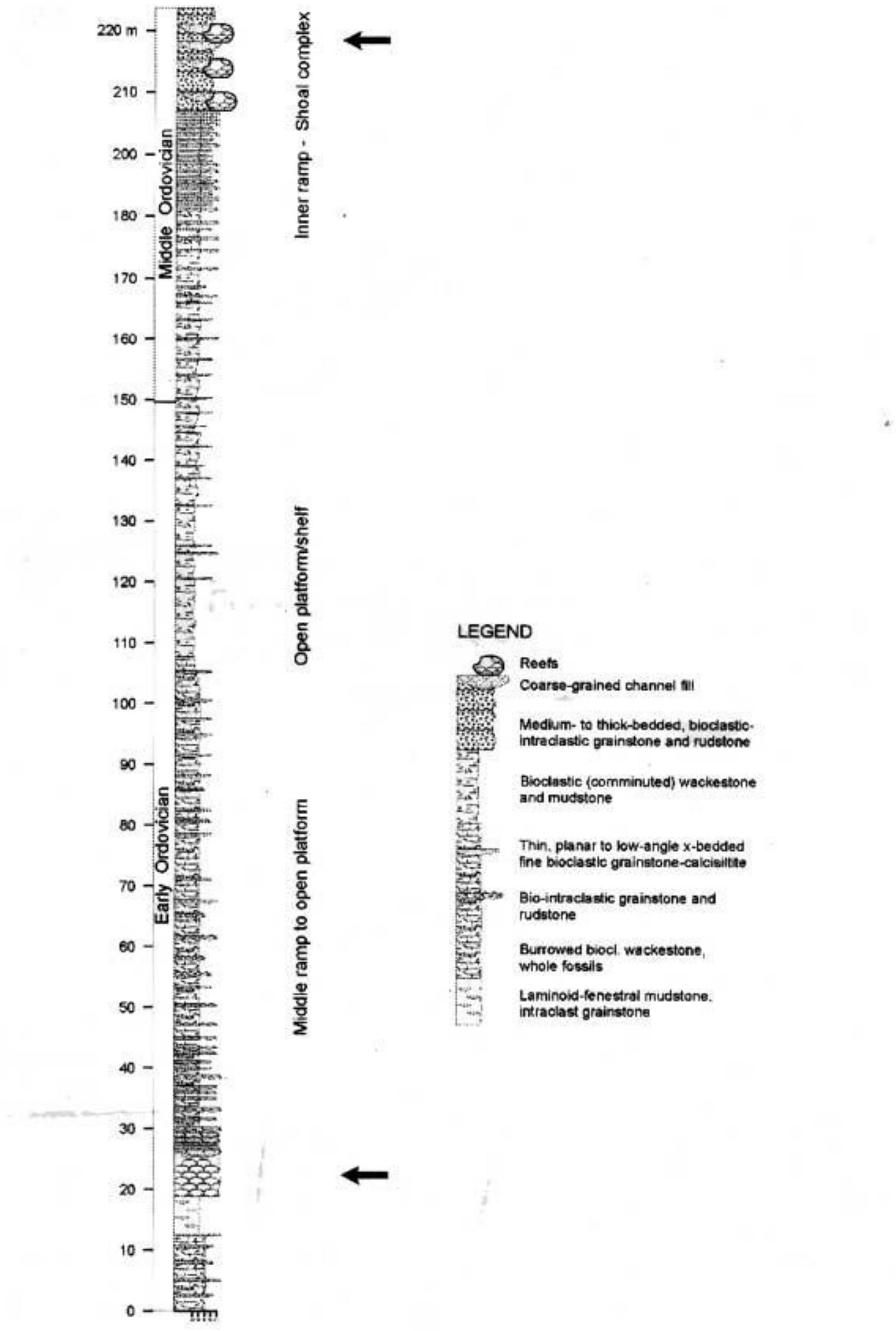

Fig. 5. Composite stratigraphic column of the San Juan Formation (lower part form Cerro La Silla, upper part form Niquivil), showing distribution of lithofacies associations. Arrows point to the lower and upper reef horizons (modified from Albanesi et al., 2003; see attached paper).

Fig. 5. Composite stratigraphic column of the San Juan Formation (lower part form Cerro La Silla, upper part form Niquivil), showing distribution of lithofacies

associations. Arrows point to the lower and upper reef horizons (modified from Albanesi et al., 2003; see attached paper).

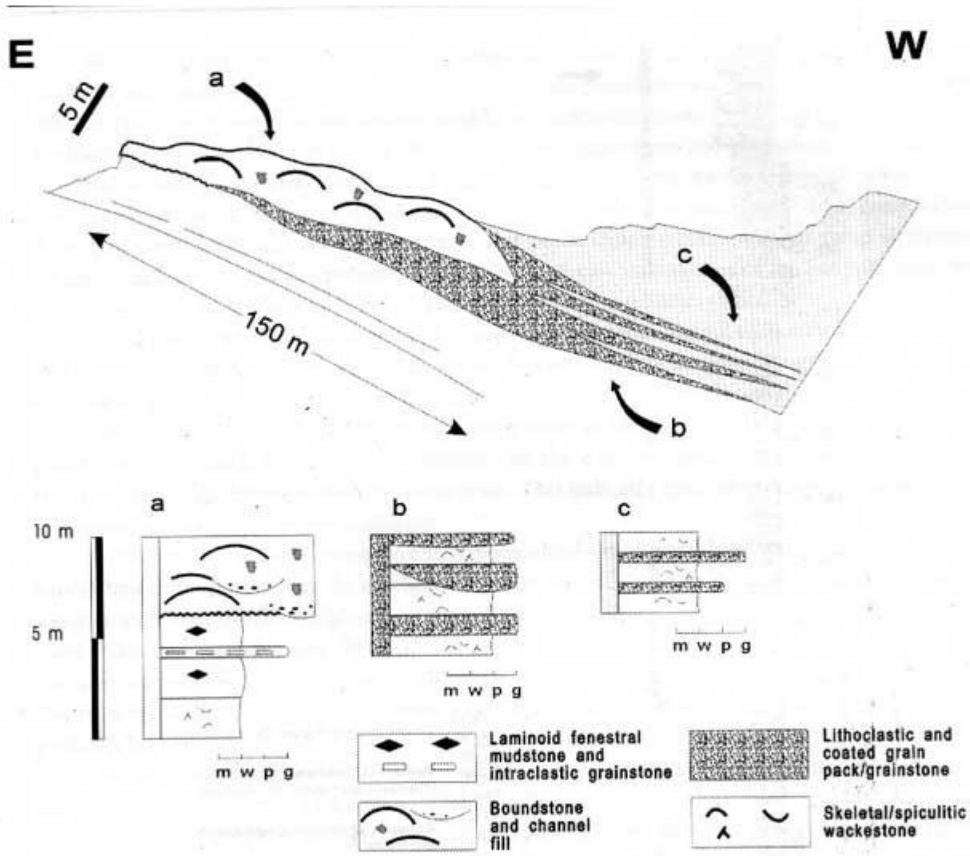

Fig. 6. Geometry and facies relationships of the lower reef horizon in a section across the western slope of Cerro La Silla. (a) Reef facies underlain by fenestral limestones (reef foundation facies), (b) reef-mound flank beds, and (c) interfingering «normal» well-bedded open platform facies of the San Juan Limestone. The top represents the present topographic surface. (Modified from Cañas and Carrera, 1993).

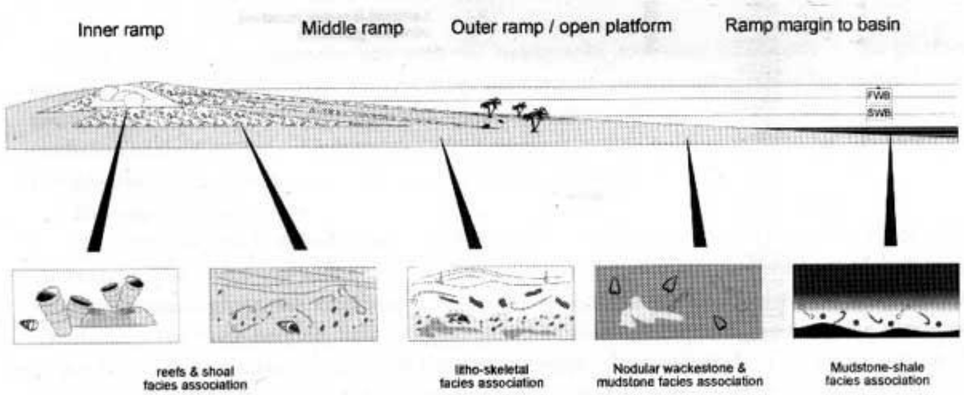

Fig. 7. Diagram showing depositional model for the San Juan Formation and inferred relationship of lithofacies associations to the fair weather and storm wave bases.

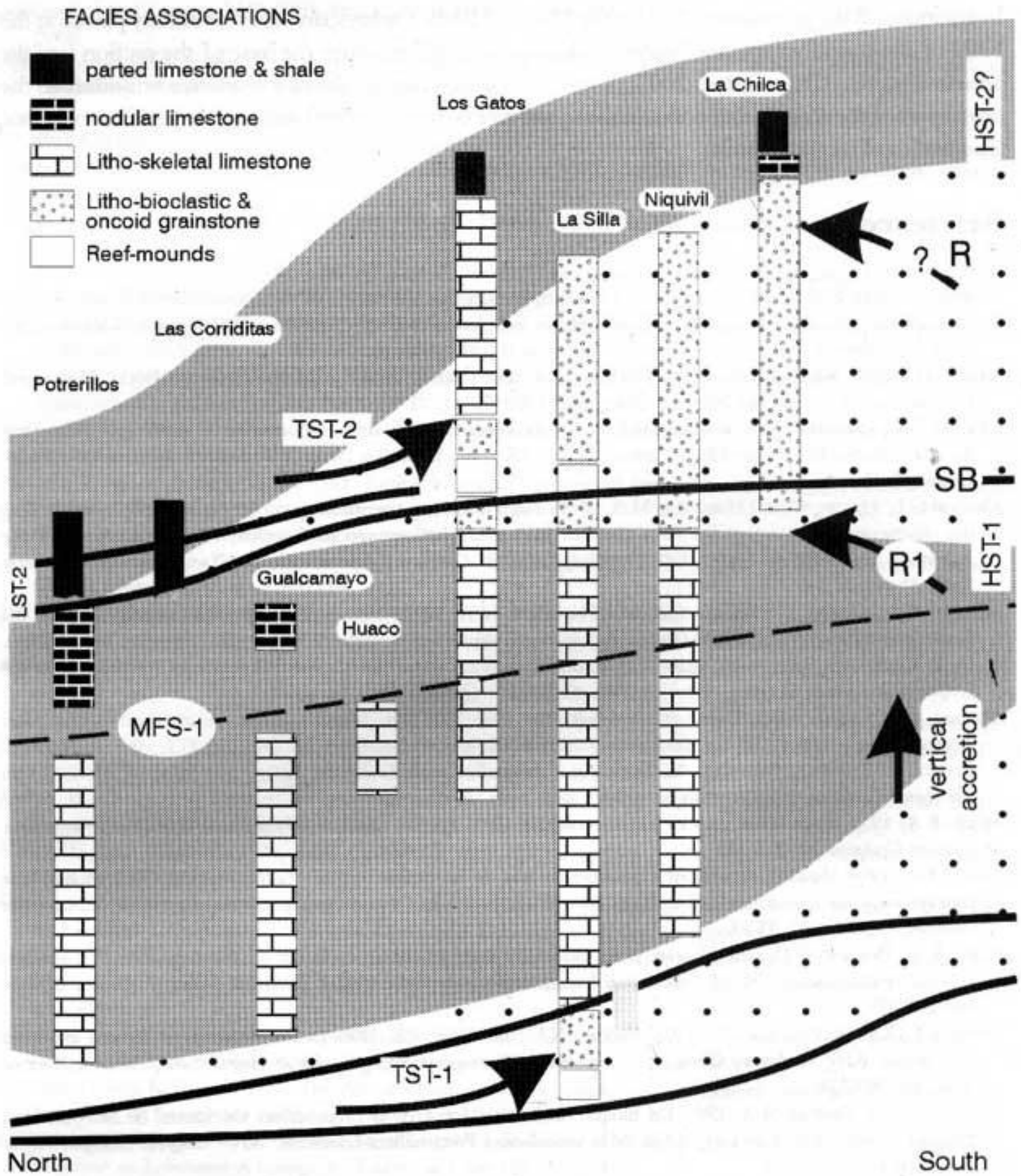

Fig. 8. Sequence stratigraphic interpretation of the San Juan Formation. Modified from Cañas (1999).

— Hike through the upper levels of the La Silla Formation (type section) to have a close view to representative lithofacies and facies sequences, microbial buildups (thrombolites), and trace fossils.

— Hike through the lower levels of the San Juan Formation (type section) examining lithologies, facies associations, and body and trace fossils. Of special interest in this section is the lower reef horizon (non-skeletal microbialites, lithistid sponges and receptaculitids).

Stop 2. Afternoon: Cerro Niquivil

The Niquivil section is included to show (1) the middle and upper levels of the San Juan

Formation; (2) the proposed *GSSP* for the Lower/Middle Ordovician Series boundary placed at the FAD of the conodont species *Protoprioniodus aranda*, at 102 m above the base of the section (see the attached paper: Albanesi *et al.,* 2003).; (3) a major facies change above a sequence boundary in the upper part of the section, that contains the upper reef horizon (skeletal and non-skeletal microbialites, *Zondarella* and receptaculitids).

References

Abbruzzi, J., Kay, S.M. and Bickford, M.E. 1993. Implications for the nature of the Precordilleran basement from Precambrian xenoliths in Miocene volcanic rocks, San Juan Province, Argentina. *XIIº Congreso Geológico Argentino y IIº Congreso de Exploración de Hidrocarburos,* Actas III, Mendoza, pp. 331-339.

Aitken, J.D. 1978. Revised models for depositional Grand Cycles, Cambrian of the Southern Rocky Mountains, Canada. *Bulletin of Canadian Petroleum Geology*, 26: 515-542.

Albanesi G.L., Hünicken, M.A. and Barnes, C.R.. 1998a. Bioestratigrafía de conodontes de las secuencias ordovícicas del cerro Potrerillo, Precordillera Central de San Juan, R. Argentina. *Actas XII Academia Nacional de Ciencias, Córdoba:* 7-72

Albanesi G.L., Ortega, G. and Hünicken, M.A. 1998b. High resolution conodont-graptolite biostratigraphy controlling the diachronous boundary between the San Juan and Gualcamayo formations (Arenig-Llanvirn) in the Argentine Precordillera. *ECOS VII (Seventh International Conodont Symposium Held in Europe,* Bologna-Modena, Italia. Abstracts: 2-4.

Albanesi G.L., Ortega, G., Barnes, C.R. and Hünicken. M.A. 1999. Conodont-graptolite biostratigraphy of the Gualcamayo Formation (Middle Ordovician) in the Gualcamayo-Guandacol rivers area, Argentina Precordillera. In: P. Kraft & O. Fatka (eds.). Quo Vadis Ordovician? Short papers of the 8th International Symposium on the Ordovician System, Prague, *Acta Univesitatis Carolinae – Geologica* 43 (1/2): 45-48.

Albanesi, G.L., Carrera, M.G., Cañas, F.L. and Saltzman, M.R. 2003. The Niquivil section, Precordillera of San Juan, Argentina, proposed *GSSP* for the Lower / Middle Ordovician boundary. *In*: Albanesi, G.L., Beresi, M.S. and Peralta, S.M. (Eds.), *Proceedings 9th International Symposium of the Ordovician System, San Juan. INSUGEO Serie Correlación Geológica,* 17, Tucumán, in press.

Astini, R.A. 1992. Tectofacies ordovícicas y evolución de la cuenca eopaleozoica de la Precordillera Argentina. *Estudios Geológicos,* 48: 315-327.

Astini, R.A. 1994. Análisis secuencial y paleoambientes de las pelitas negras (aloformación Gualcamayo) que suprayacen a las sucesiones carbonáticas eo-ordovícicas en la Precordillera argentina. *Revista de la Asociación Geológica Argentina,* 49: 71-84.

Astini, R.A., Benedetto, J.L. and Vaccari, N.E. 1995. The early Paleozoic evolution of the Argentine Precordillera as a Laurentian rifted, drifted, and collided terrane: a geodynamic model. *Geological Society of America Bulletin,* 107: 253-273.

Astini, R.A., Ramos, V.A., Benedetto, J.L., Vaccari, N.E. and Cañas, F.L. 1996. La Precordillera: un terreno exótico a Gondwana. XIIIº Congreso Geológico Argentino, *IIIº Congreso de Exploración de Hidrocarburos*, Actas 5, Buenos Aires, pp. 293-324.

Astini, R.A. and Thomas, W.A. 1999. Un bloque cámbrico inferior en la Precordillera Occidental de San Juan con afinidad Apalachiana: nueva evidencia de la vinculación Precordillera-Laurentia. *XIVº Congreso Geológico Argentino*, Actas I, Salta, pp. 56.

Baldis, B.A., Bordonaro, O.L., Beresi, M.S. and Uliarte, E. 1981. Zona de dispersión estromatolítica en la secuencia calcáreo-dolomítica del Paleozoico Inferior de San Juan. *VIIIº Congreso Geológico Argentino,* Actas II, San Luis, pp. 419-434.

Buggisch, W., Keller, M. and Lehnert, O. 2003. Carbon isotope record of Late Cambrian to Early Ordovician carbonates of the Argentine Precordillera. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 195: 357-373.

Cañas, F.L. 1995. Early Ordovician carbonate platform facies of the Argentine Precordillera: restricted shelf to open platform evolution. *In:* J.D. Cooper, M.L. Droser and S.C. Finney (Eds.), *The Ordovician Odyssey: Las Vegas, 7th International Symposium on the Ordovician System*, Society of Economic Paleontologists and Mineralogists, Pacific Section, Book, 77, pp. 221-224.

Cañas, F.L. 1999. Facies and sequences of the Late Cambrian - Early Ordovician carbonates of the Argentine Precordillera: a stratigraphic comparison with Laurentian platforms. *In:* V.A. Ramos and J.D. Keppie (Eds.), *Laurentia-Gondwana connections before Pangea. Geological Society of America, Special Paper* 336, Colorado, pp. 43-62.

Cañas, F.L. and Carrera, M.G. 1993. Early Ordovician microbial-sponge-receptaculitid bioherms of the Precordillera, Western Argentina. *Facies*, 29: 169-178.

Cañas, F.L. and Carrera, M.G. 2003. Precordilleran reefs. *In*: Benedetto, J.L. (Ed.): *Ordovician Fossils of Argentina,* in press.

Carrera, M.G. 2001. Análisis de la distribución y composición de las biofacies de la Formación San Juan (Ordovícico Temprano), Precordillera Argentina. *Ameghiniana*, 38: 169-184.

Cech, N. and Carrera, M.G. 2002. Dinámica de las comunidades arenigianas de la Formación San Juan (Ordovícico), Precordillera Argentina. *Ameghiniana*, 39: 21-40.

Chow, N. and James, N.P. 1987. Cambrian Grand Cycles: a north Appalachian perspective. *Geological Society of America Bulletin*, 98: 418-429.

Dalziel, I.W.D., Dalla Salda, L.H., Cingolani, C.A. and Palmer, A.R. 1996. The Argentine Precordillera: a Laurentian terrane? *GSA Today,* 6: 16-18.

del Papa, C.E. 1988: *Estratigrafía y sedimentología de la secuencia Ordovícica aflorante en el área de Niquivil, San Juan*. Unpub. graduate Thesis, Universidad Nacional de Córdoba, Córdoba.

Demicco, R.V. 1985. Platform and off-platform carbonates of the Upper Cambrian of western Maryland, U.S.A. *Sedimentology*, 32: 1-22.

Finney, S.C., Gleason, J., Gehrels, G., Peralta, S. and Aceñolaza, G.F. 2003. Early Gondwanan connection for the Argentine Precordillera terrane. *Earth and Planetary Science Letters,* 205: 349-359.

Gosen, W.von 1992. Structural evolution of the Argentine Precordillera: the Rio San Juan section. *Journal of Structural Geology,* 14: 643-667.

Herrera, Z.A. and Benedetto, J.L. 1991. Early Ordovician brachiopod faunas of the Precordillera Basin, Western Argentina: biostratigraphy and paleobiogeographical affinities. *In:* D.I. Mackinnon, D.E. Lee and J.D. Campbell (Eds.), *Brachiopods through time,* Balkema, pp. 283-301.

Hünicken, M.A. 1985. Lower Ordovician conodont biostratigraphy in Argentina. *Boletín Academia Nacional de Ciencias, Córdoba,* 56 (3-4): 309-321.

Jordan, T.E., Isacks, B.L., Allmendinger, R.W., Brewer, J.A., Ramos, V.A. and Ando, C.J. 1983. Andean tectonics related to geometry of subducted Nazca plate. *Geological Society of America Bulletin*, 94: 341-361.

Keller, M. 1999. Argentine Precordillera: sedimentary and plate tectonic history of a Laurentian crustal fragment in South America. *Geological Society of America, Special Paper* 341, Boulder, 131 pp.

Keller, M., Buggisch, W. and Bercowski, F. 1989. Facies and sedimentology of Upper Cambrian shallowing-upward cycles in the La Flecha Formation (Argentine Precordillera). *Zentralblatt für Geologie und Paläontologie* Teil I (H. 5/6): 999-1011.

Keller, M., Cañas, F.L., Lehnert, O. and Vaccari, N.E. 1994. The Upper Cambrian and Lower Ordovician of the Precordillera (Western Argentina): Some stratigraphic reconsiderations. *Newsletters on Stratigraphy,* 31: 115-132.

Keller, M. and Flügel, E. 1996. Early Ordovician reefs from Argentina: stromatoporoid vs. stromatolite origin. *Facies*, 34: 177-192.

Lehnert, O. (1990): *Conodontenstratigraphie und Fazies der Formation San Juan bei Niquivil (Unteres Ordoviz, Argentinien, Pr,,kordillere).* Unbup. graduate Thesis, Universität Erlangen-Nürnberg, Erlangen. 171 pp.

Lehnert, O. 1993. Bioestratigrafía de los conodontes arenigianos de la Formación San Juan en la localidad de Niquivil (Precordillera Sanjuanina, Argentina) y su correlación intercontinental. *Revista Española de Paleontlogía*, 8: 153-164.

Lehnert, O. 1995. Ordovizische Conodonten aus der Präkordillere Westargentiniens: ihre Bedeutung für Stratigraphie und Paläogeographie. *Erlanger geologische Abhandlungen*, 125: 1-193.

Lehnert, O. and Keller, M. 1993. The conodont record of the Argentine Precordillera: problems and possibilities. *Zentralblatt für Geologie und Paläontologie,* Teil I H. 1 (2): 231-244.

Lehnert, O. and Keller, M. 1993. Posición estratigráfica de los arrecifes arenigianos en la Precordillera Argentina. *Documents du Laboratoire de Géologie de l'Univers. de Lyon,* 125: 263-275.

Lehnert, O., Miller, J.F. and Repetski, J.E. 1997. Paleogeographic significance of *Clavohamulus hintzei* Miller (Conodonta) and other Ibexian conodonts in an Early Paleozoic carbonate platform facies of the Argentine Precordillera. *Geological Society of America Bulletin,* 109: 429-443.

Markello, J.R. and Read, J.F. 1982. Upper Cambrian intrashelf basin, Nolichucky Formation, southwest Virginia Appalachians. *American Association of Petroleum Geologists Bulletin,* 66: 860-878.

Mazzullo, S.J., Agostino, P., Seitz, J.N. and Fisher, D.W. 1978. Stratigraphy and depositional environments of the Upper Cambrian - Lower Ordovician sequence, Saratoga Springs, New York. J*ournal of Sedimentary Petrology,* 48: 99-116.

Melchor, R.N., Sato, A.M., Llambías, E.J. and Tickyj, H. (1999). Documentación de la extensión meridional del terreno Cuyania/Precordillera en la Provincia de La Pampa. *XIVº Congreso Geológico Argentino, Actas* I, Salta, pp. 156-159.

Sarmiento, G.N. 1985. La Biozona de Amorphognathus variabilis-Eoplacognathus suecicus (Conodonta), Llanvirniano inferior, en el flanco oriental de la Sierra de Villicum. *Primeras Jornadas sobre Geología de Precordillera, San Juan,* Actas: 119-123.

Thomas, W.A. and Astini, R.A. 1996. The Argentine Precordillera: a traveler from the Ouachita Embayment of North American Laurentia. *Science*, 283: 752-757.

Thomas, W.A. and Astini, R.A. 2003. Ordovician accretion of the Argentine Precordillera terrane to Gondwana: a review. *Journal of South American Earth Sciences,* 16: 67-79.

Vaccari, N.E. (1994): *Las faunas de trilobites de las sucesiones carbonáticas del Cámbrico tardío y Ordovícico temprano de la Precordillera Septentrional, República Argentina.* Unbub. Ph.D. Thesis, Universidad Nacional de Córdoba, Córdoba. 271 p.

Vaccari, N.E. 2001. Trilobites de la Formación San Juan (Ordovícico Inferior), Precordillera Argentina. Ameghiniana, 38: 331-347.